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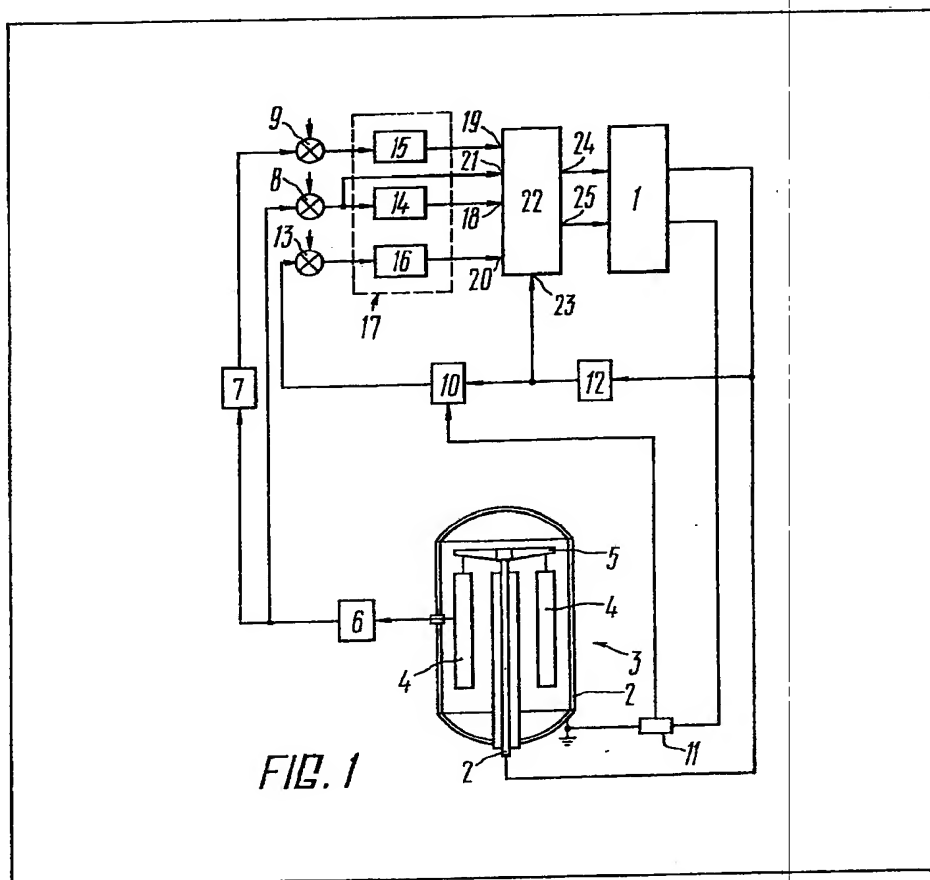
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(54) Method of control of  
 chemico-thermal treatment of  
 workpieces in glow discharge and a  
 device for carrying out the same

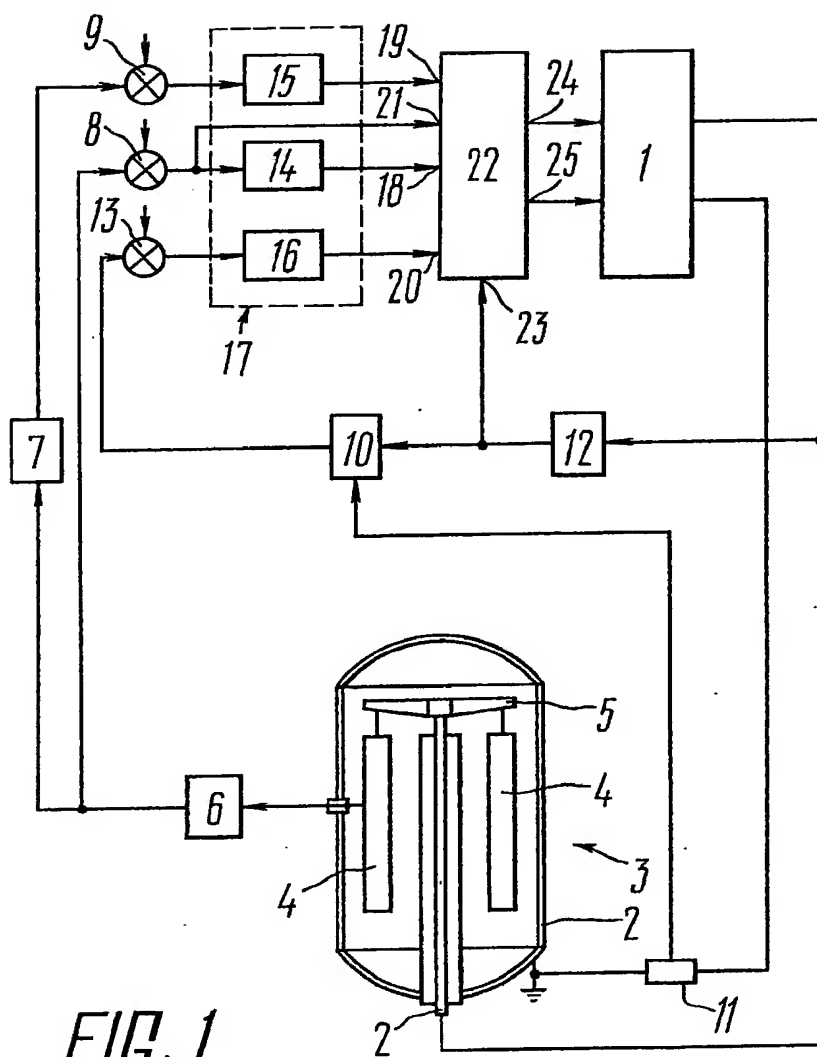
(57) The method comprises measuring

the workpiece temperature, its rate of  
 change and the frequency of arc occur-  
 rence, comparing said measured quanti-  
 ties with their predetermined values,  
 producing the corresponding error sig-  
 nals, and obtaining a control signal  
 from the latter to control the glow  
 discharge voltage.

Sensors (6,7,10) adapted to sense the  
 temperature of workpieces (4) its rate of  
 change and the frequency of arc occur-  
 rence respectively output to elements  
 (8,9,13) where said measured quantities  
 and compared with their predetermined  
 values. The comparison elements  
 (8,9,13) output to regulators (14,15,16)  
 coupled to a supply voltage source (1)  
 via a control unit (22). The control unit  
 (22) determines the combination of the  
 outputs 18, 19, 20 to be used to control  
 the voltage source (1).



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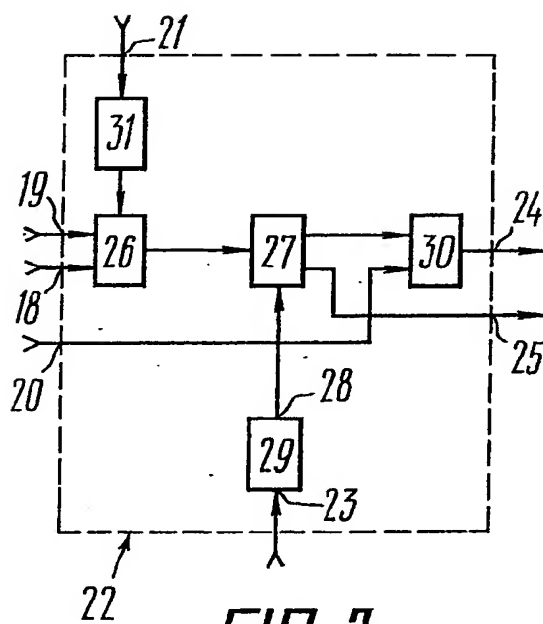


FIG. 2

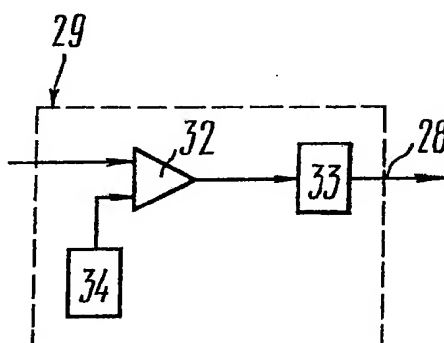
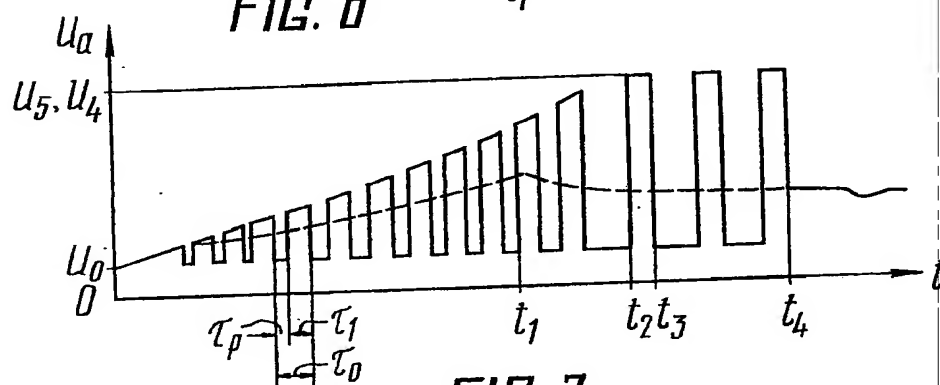
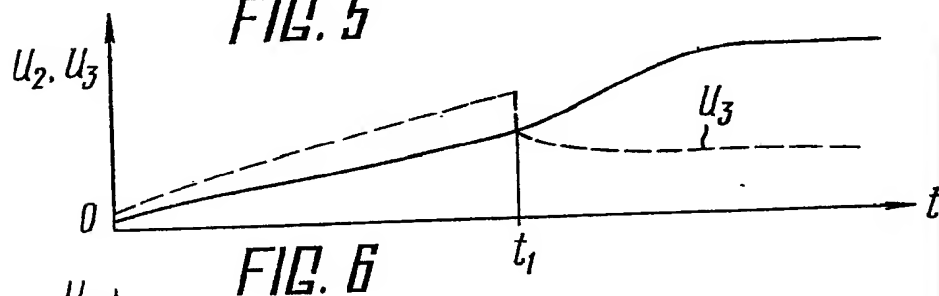
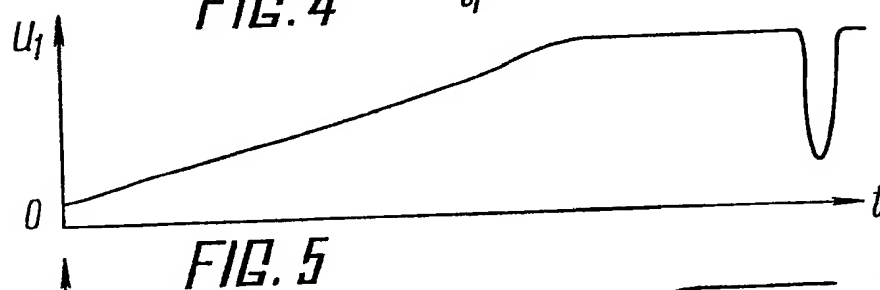
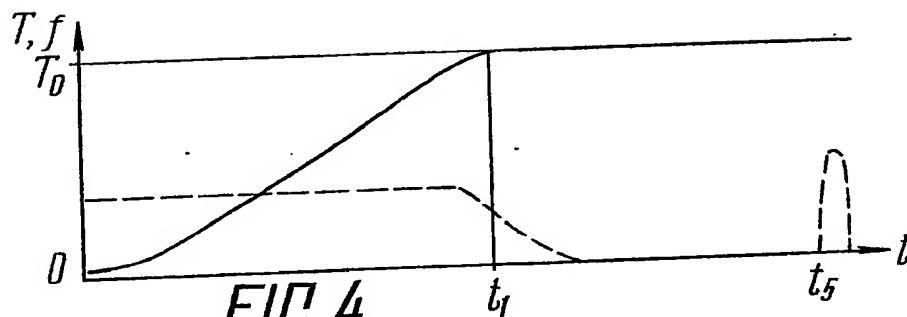


FIG. 3



## SPECIFICATION

**Method of control of chemio-thermal treatment of workpieces in glow discharge and a device for carrying out the method**

The invention relates to heat treatment, and more particularly to methods and devices for control of chemico-thermal treatment of articles in glow discharge.

The method and device of the invention include applications concerned, for example, with control of treatment of workpieces in ion nitration installations used to machine building and aviation industries in order to attain higher workpiece strength.

According to the invention there is provided a method of control of chemico-thermal treatment of workpieces in a glow discharge comprising the steps of measuring the temperature of the workpieces and the rate of change of said temperature, comparing said measured quantities with their predetermined values, producing the corresponding error signals, and obtaining a control signal from said error signals to control the glow discharge voltage, which method comprises, in accordance with the invention, a step of measuring, concurrent with the measuring step above, the frequency of occurrence of arc in the glow discharge, comparing said measured frequency with a predetermined value, producing the corresponding error signal, obtaining another control signal from said error signal, and using said another control signal to control the frequency of arc occurrence.

Advantageously, the method of the invention should be provided with steps of using, since the beginning of the treatment of the workpiece till the end of the cathode sputtering, for the glow discharge voltage a pulsed voltage with adjustable amplitude and average values thereof, using the average value of said pulsed voltage in controlling the temperature and its range of change, and using the amplitude values of said pulsed voltage in controlling the frequency of arc occurrence, thereby providing for an intense cathode sputtering.

Preferably, the method of invention should be provided with steps of comparing the arc occurrence frequency-dependent signal adapted to control the glow discharge voltage with the temperature-dependent control signal or the rate-of-change-of-temperature-dependent control signal and controlling the glow discharge voltage by using that one of said control signals being compared which corresponds to a lesser glow discharge voltage, thereby providing for better quality of simultaneous control of at least two characteristics of treatment.

Advantageously, the method of the invention should be provided with a step of decreasing the given value of the arc occurrence frequency when the workpiece temperature is increased.

According to the invention there is provided a device for carrying out the method of the invention comprising a supply voltage source connected to leads of a discharge chamber which houses the workpieces, a workpiece temperature sensor, a rate-of-change-of-temperature sensor, elements

adapted to compare respectively the measured temperature and the rate of change thereof with predetermined values of said quantities, and a regulator unit, the outputs of the sensors being connected via their respective comparison elements to said regulator unit which is connected to said supply voltage source, which device comprises, according to the invention, an arc occurrence frequency sensor, an element adapted to compare the frequency of arc occurrence with its predetermined value, a control unit, and a glow discharge voltage transmitter, said regulator unit including regulators adapted to adjust respectively the workpiece temperature, the rate of change thereof and the frequency of arc occurrence, the arc occurrence frequency sensor being connected to the arc occurrence frequency regulator via its corresponding comparison element, the output of the arc occurrence frequency regulator being coupled to a respective one of the inputs of the control unit which has another two inputs coupled respectively to the outputs of the temperature regulator and the rate-of-change-of-temperature regulator, has yet another input thereof coupled to the output of the temperature comparison element, has the remaining input thereof coupled via the glow discharge voltage transmitter to a respective one of said leads, and has its outputs coupled to the supply voltage source.

Advantageously, the device of the invention should have its control unit comprising two switches, a null detector, a minimal signal extractor, and an end-of-cathode sputtering acknowledgement circuit, the output of the null detector being connected to a first input of a first one of said switches which has its output connected to a first input of a second one of said switches, said second switch having its second input coupled to the output of the end-of-cathode sputtering acknowledgement circuit, and having a first output connected to a first input of the minimal signal extractor, the respective inputs of the first switch, the input of the null detector, a second input of the minimal signal extractor, and the input of the end-of-cathode sputtering acknowledgement circuit being used respectively as the inputs of the control unit, and a second output of the second switch and the output of the minimal signal extractor being used respectively as the outputs of the control unit.

Preferably, the device of the invention should have its end-of-cathode sputtering acknowledgement circuit comprising a comparator, a reference voltage source and a time counter, a first input and the output of the comparator being connected respectively to the reference voltage source and to the input of the time counter, a second input of the comparator and the output of the time counter being used respectively as the input and the output of the end-of-cathode sputtering acknowledgement circuit.

The invention will now be described in more detail, by way of example, with reference to the accompanying drawings, in which:

*Figure 1* shows a block diagram of a device for chemico-thermal treatment of workpieces in a glow discharge, according to the invention;

*Figure 2* shows a block diagram of a control unit of the device of the invention;

Figure 3 shows an embodiment of an end-of-cathode sputtering acknowledgement circuit of the device of the invention;

Figure 4 discloses a time-versus-workpiece temperature and arc occurrence frequency diagram, according to the invention;

Figure 5 discloses a time-versus-arc occurrence frequency-dependent control signal, according to the invention;

Figure 6 shows a diagram relating time to temperature-dependent control signal and to rate-of-change-of-temperature-dependent control signal, according to the invention; and

Figure 7 shows a time-versus-supply voltage diagram, according to the invention.

The method of the invention will be described in the following with reference to the drawings that disclose a device for carrying out the method.

Referring to Figure 1, the device of the invention comprises a supply voltage source 1 having its outputs connected to leads 2 of a discharge chamber 3 in which workpieces 4 are subject to a chemico-thermal treatment. The workpieces 4 in the chamber are connected with suspension members 5. The wall of the chamber 3 serves as one the leads 2. The device of the invention also comprises a temperature sensor 6 having its input coupled to the workpiece 4. A thermocouple with an amplifier can be used as the temperature sensor 6, which has its output connected to the input of a rate-of-change-of-temperature sensor 7 and to a first input of a temperature comparison element 8. The output of the sensor 7 is connected to a first input of a rate-of-change-of-temperature comparison element 9. There is an arc occurrence frequency sensor 10 which has its inputs connected to the outputs of the glow discharge current transmitter 11 and a glow discharge voltage transmitter 12. The output of the sensor 10 is connected to a first input of an arc occurrence frequency comparison element 13. The second inputs of the comparison elements 8, 9, 13 are used to receive signals that correspond to predetermined values of the workpiece temperature, its rate of change and frequency of arc occurrence. The outputs of the comparison elements 8, 9, 13 are connected to the inputs of their respective regulators 14, 15, 16 of a regulator unit 17 which is designed to produce control signals relating to the workpiece temperature, its rate of change and frequency of arc occurrence, depending on the error signals available to the outputs of the comparison elements 8, 9, 13. The outputs of the regulators 14, 15, 16 and the output of the comparison elements 8 are connected respectively to inputs 18, 19, 20, 21 of a control unit 22 whose input 23 is coupled to the output of the transmitter 12. Outputs 24, 25 of the control unit are connected to the inputs of the supply voltage source 1.

The control unit 22 is designed to control the amplitude and average values of the supply voltage.

Referring to Figure 2, the control unit comprises a switch 26 having its output coupled to a first input of a switch 27. The latter has its second input coupled to an output 28 of an end-of-cathode sputtering acknowledgement circuit 29, and has its first output

connected to a first input of a minimal signal extractor 30. A first input of the switch 26 is connected to the output of a null detector 31. Two other inputs of the switch 26, the input of the null detector 31, a second input of the minimal signal extractor 30 and the input of the end-of-cathode sputtering acknowledgement circuit 29 are used respectively as inputs 18, 19, 21, 20, 23 of the control unit 22. The output of the minimal signal extractor 30 and a second output of the switch 27 are used respectively as outputs 25 and 24 of the control unit 22. The switch 26 is used to connect the output of one of the regulators, 14 or 15, Figure 1, to the corresponding input of the switch 27 (Figure 2) which is used to connect the output of one of the regulators, 14 or 15, Figure 1, to the corresponding input of the minimal signal extractor 30 or directly to the input 25 of the control unit 22, depending on the presence of a signal at the output 28 of the circuit 29. The extractor 30 operates to compare signals applied to its inputs and select that one of them which has a lesser amplitude.

Figure 3 shows an embodiment of the end-of-cathode sputtering acknowledgement circuit 29 comprising a comparator 32 having its output coupled to the input of a time counter 33. The comparator 32 has a first input connected to a reference voltage source 34 and has its second input used as the input 23 of the control unit 22. The output of the time counter 33 serves as the output 28 of the circuit 29. The comparator 32 operates to compare the supply voltage with the reference voltage from the source 34 corresponding to the given value of the glow discharge voltage. In addition, the comparator 32 produces a signal for actuation of the time counter 33. The latter counts the time during which cathode sputtering is carried out in the presence of a signal at the output of the comparator 32, and produces a signal applied to the input of the switch 27 (Figure 2) on completion of cathode sputtering.

Figures 4 to 7 discloses time diagrams depicting the operation of a control device that exercises control over ion nitrition furnaces.

Figure 4 shows how temperature  $T$  (solid line) of the workpieces 4 in Figure 1 and frequency of arc occurrence,  $f$ , (dashed line) vary with time. The abscissa axis reads the current values of time  $t$ , while the ordinate axis reads the values of  $T$ ,  $f$  and  $T_0$ . The ordinate  $T_0$  stands for the given temperature of the workpiece 4 (Figure 1).

Figure 5 shows how control signal  $U_1$  at the output of the arc occurrence frequency regulator 16 (Figure 1) varies with time.

Figure 6 discloses how control signal  $U_2$  (solid line) at the output of the rate-of-change-of-temperature regulator 15 and control signal  $U_3$  (dashed line) at the output of the temperature regulator 14 vary with time.

Figure 7 shows how supply voltage  $U_0$  varies with time. In the Figure, solid line depicts voltage envelope form, while dashed line depicts the voltage averaged for the period. The ordinate  $U_4$  stands for the supply voltage at which an intense cathode sputtering takes place.

The ordinate axis reads values  $t_1, t_2, t_3, t_4, t_5$

corresponding to the following points in time:

$t_1$  is the point in time when the heating temperature reaches the given value;

$t_2$  is the point in time when the amplitude value of the supply voltage reaches  $U_a$ ;

$t_3$  is the point in time corresponding to the beginning of a space interval between two successive pulses;

$t_4$  is the point in time corresponding to the end of cathode sputtering; and

$t_5$  is the point in time corresponding to the beginning of the next occurrence of arc discharge.

In the Figure, the letters  $\tau_p$ ,  $\tau_1$  and  $\tau_o$  stand for the space interval, pulse length, and pulse cycle period, respectively.

The method of the invention is carried out by the device of Figures 1, 2, 3 in the following manner.

At the initial point in time  $t=0$  (Figures 4-7), a supply voltage from the source 1 is applied to the leads 2 (Figure 1) of the discharge chamber 3 which has its value equal to the initial value of  $U_o$  (Figure 2) corresponding to the initial values of the control signals at the inputs of the source 1. There usually result frequent transformations of glow discharge into arc one at the beginning of the treatment. Quenching the arc discharge is as follows. The supply voltage is allowed to quickly drop down to zero for a short time interval and is then applied anew after the time sufficient for the discharge gap to attain a deionization condition. To this end, the control signal at the corresponding input of the source 1 coupled to the output 24 of the control unit 22 is reduced to zero and is then increased after a certain delay time. The occurrence of arc discharge results in an increase of the discharge current and in a decrease of the discharge voltage. As a result, the signals produced by the current transmitter 11 (Figure 1) and the voltage transmitter 12 indicate the occurrence of arc discharge. The output of the arc occurrence frequency sensor 10 produces a signal which is proportional to the rate at which arc discharge occur (the frequency of arc occurrence). That signal is applied to a respective input of the arc occurrence frequency comparison element 13 in which it is compared with the signal proportional to the given frequency of arc occurrence. As a result, the output of the element 13 produces a signal proportional to the difference between the given and measured values of the frequency of arc occurrence.

The signal above is applied to the input of the arc occurrence frequency regulator 6 whose output produces, in accordance with the selected law of regulation, signal  $U_1$  (Figure 5) which is employed to control the source 1 (Figure 1) so as to vary the amplitude value,  $U_a$ , (Figure 7) of the supply voltage pulses. A proportional and integral regulator can be used as the regulator 16 (Figure 1). The signal produced by the regulator 16 is applied to the input 20 of the control unit 22, said input being used as one of the inputs of the minimal signal extractor 30 (Figure 2). The other input of the extractor 30 receives a signal from the switch 27 that performs, in addition to its basic application, a function of a reference signal source. That signal has a constant value considerably exceeding the value of the signal

at the input 20 of the control unit 22. The minimal signal extractor 30 operates to compare the signals at its inputs, with the results that its output works out a smaller signal among those being compared; in the case under consideration, the smaller signal is obtained from the output of the arc occurrence frequency regulator 16. This signal is applied to the input 24 of the supply voltage source 1 and tends to vary the value of  $U_2$  (voltage amplitude, Figure 7) in a manner such that the frequency of arc occurrence is held at a given level. Note that  $U_a$  is increased in our case.

During the treatment, the workpiece 4 (Figure 1) are heated up. This results in the appearance at the outputs of the temperature sensor 6 and the rate-of-change-of-temperature sensor 7 of signals that are proportional to the actual values of the workpiece temperature and its rate of change. The comparison elements 8, 9 operate to compare these signals with the signals proportional to the given values of the quantities above. Thereafter, the outputs of the comparison elements 8, 9 produces error signals relating to the workpiece temperature and its rate of change.

In accordance with these error signals and the selected laws of regulation, the regulators 14, 15 produce signals  $U_2$  and  $U_3$  (Figure 6) which are used to control the average value of the supply voltage. Proportional and integral regulators can be used as the regulators 14, 15. The produced control signals are applied to the inputs 18, 19 (Figure 1) of the control unit 22 used as the respective inputs of the switch 26 (Figure 2). The latter operates so that prior to point in time  $t_1$  only the rate-of-change-of-temperature-dependent control signal  $U_2$  is allowed to be supplied to the corresponding input of the switch 27. This signal passes from the output of the regulator 15 via the switch 27 to the input 25 of the supply voltage 1. As a result, the average value  $U_s$  of the supply voltage is changed. This results in a change of the average value of the discharge voltage, and the rate of heating is thus held at a given level. One can vary the average value  $U_s$  by changing, for example, the space interval between pulses,  $\tau_p$ , with the pulse length,  $\tau_1$ , and the pulse cycle period,  $\tau_o$ , kept constant.

At the point in time  $t_1$  (Figure 4), workpiece temperature  $t$  reaches a predetermined value of  $T_o$ . This results in the appearance at the output of the null detector 31 (Figure 2) of a signal that switches over the switch 26 in a manner such that the output of the latter produces control signal  $U_3$  produced by the temperature regulator 14.

It is desirable that the transfer from control signal  $U_2$  to control signal  $U_3$  be carried out in a smooth fashion. This means that the initial value of  $U_3$  is equal to the value of  $U_2$  available at the moment of transfer. There results, therefore, a condition at the point in time  $t_1$  in which control signal  $U_3$  (Figure 6) from the temperature regulator 14 is applied to the input 25 of the supply voltage source 1. This causes a variation of the average value of the discharge voltage such that workpiece temperature is held at the given level  $T_o$ .

At the point in time  $t_2$  (Figure 7) the amplitude

value of the supply voltage,  $U_a$ , reaches  $U_4$ , which provides for an intense cathode sputtering. The signal at the input 23 of the end-of-cathode sputtering acknowledgement circuit 29, i.e. at one input of the comparator 32 (Figure 3) becomes equal to the signal delivered to the other input of the comparator and the latter thus produces a signal that drives the time counter 33. At the point in time  $t_3$  (Figure 7), the signal at the output of the comparator 32 (Figure 3) ceases, and the counter 33 stops counting. Thus the counter 33 counts the time during which the discharge voltage is held at the level  $U_4$  (Figure 4).

At the point in time  $t_4$  the time counted by the counter 33 (Figure 3) reaches a predetermined value, and the output 28 of the circuit 29 produces a signal that switches over the switch 27 (Figure 2). This causes interchange of the signals at the outputs of the switch 27. Thus the input 25 (Figure 1) of the supply voltage source 1 receives a constant signal at which the discharge voltage has practically continuous shape while the first input of the minimal signal extractor 30 receives a signal produced by the temperature regulator 14. The signal produced by the arc occurrence frequency regulator 16 is always received by the second input of the extractor 30 whose output produces a smaller signal (in amplitude) among the two input signals. When no arc discharge occurs, the smaller signal is a temperature-dependent control signal  $U_3$ . The workpiece temperature is then maintained at the given level  $T_0$  (Figure 4) by varying supply voltage (Figure 7) of a continuous waveform.

If arc discharge occurs again at the point in time  $t_5$  (Figures 4, 5, 7), then the output signal  $U_1$  (Figure 5) of the arc occurrence frequency regulator 16 (Figure 1) decreases. When that signal reaches a smaller value than the signal  $U_3$  (Figure 6) produced by the temperature regulator 14 the supply voltage decreases and the frequency of arc occurrence thus decreases too.

It is good practice to reduce the frequency of arc occurrence during heating since adverse effect of arc discharge is enhanced as the temperature increases. It is necessary in this case to connect the setting input of the arc occurrence frequency comparison element 13 to the input of the temperature sensor 6 (this connection is not shown in Figures 1, 2, 3).

The method and device of the invention make it possible to exercise control over the treatment, prior to termination of cathode sputtering, by using two control parameters simultaneously, i.e. the frequency of arc occurrence and the workpiece temperature or the frequency of arc occurrence and the rate of change of the workpiece temperature in which case the amplitude and average values of the supply voltage are subject to control action. This allows for the use of an intense cathode sputtering at higher voltage, with the result that the treatment time is decreased and the workpiece quality is increased.

The device of the invention has an individual regulator for each control parameter, which provides for better control action and higher quality of workpiece treatment.

## 65 CLAIMS

1. A method of control of chemico-thermal treatment of workpieces in a glow discharge comprising the steps of measuring the temperature of the workpieces, the rate of change of said temperature and the frequency of occurrence of arc in the glow discharge, comparing said measured quantities with their predetermined values, producing the corresponding error signals, obtaining control signals from said error signals to control the glow discharge voltage in terms of said temperature, its rate of change and said frequency of arc occurrence, and using the arc occurrence frequency-dependent control signal for the control of the occurrence of arc in the glow discharge.

2. A method as claimed in claim 1, wherein workpieces held in a glow discharge are subject simultaneously to heating and cathode sputtering, which method comprises the steps of using for the glow discharge voltage a pulsed voltage with adjustable amplitude and average values thereof since the beginning of the treatment of the workpiece till the end of the cathode sputtering, using the average value of said pulsed voltage in controlling the temperature and its rate of change, and using the amplitude value of the pulsed voltage in controlling the frequency of arc occurrence.

3. A method as claimed in claims 1 and 2, comprising the steps of comparing the arc occurrence frequency-dependent control signal to control the glow discharge voltage with the temperature-dependent control signal and controlling the glow-discharge voltage by using that one of said control signals which corresponds to a lesser glow discharge voltage.

4. A method as claimed in claims 1 and 2, comprising the steps of comprising the arc occurrence frequency-dependent control signal to control the glow discharge voltage with the rate-of-change-of-temperature-dependent control signal and controlling the glow discharge voltage by using that one of said control signals being compared which corresponds to a lesser glow discharge voltage.

5. A method as claimed in claim 1, wherein the given value of the arc occurrence frequency is decreased with increasing temperature of the workpiece.

6. A device for carrying out the method as claimed in claims 1, 2, 3, 4, 5 comprising a supply voltage source connected to leads of a discharge chamber which houses workpieces, a workpiece temperature sensor, a rate-of-change-of-temperature sensor, an arc occurrence frequency sensor, elements adapted to compare the measured quantities representing respectively the temperature, the rate of change of the temperature and the frequency of arc occurrence with predetermined values of said quantities, regulators adapted to regulate respectively the temperature, the rate of change of temperature, and the frequency of arc occurrence, a control unit, and a glow discharge voltage transmitter, the outputs of said sensors being connected via their corresponding comparison elements to their respective regulators, the output of the arc occurrence frequency regulator



being connected to a respective one of the inputs of the control unit which has another two inputs coupled respectively to the outputs of the temperature regulator and the rate-of-change-of-

- 5 temperature regulator, has yet another input coupled to the temperature comparison element, has the remaining input coupled via the glow discharge voltage transmitter to a respective one of said leads, and has its outputs coupled to the supply source.
- 10 7. A device as claimed in claim 6, wherein the control unit includes two switches, a null detector, a minimal signal extractor, and an end of cathode sputtering acknowledgement circuit, the output of the null detector being connected to a first input of a
- 15 first one of said switches which has its output connected to a first input of a second one of said switches, said second switch having its second input coupled to the output of the end-of-cathode sputtering acknowledgement circuit, and having a first
- 20 output connected to a first input of the minimal signal extractor, the inputs of the first switch, the input of the null detector, a second input of the minimal signal extractor, and the input of the end-of-cathode sputtering acknowledgement circuit
- 25 being used respectively as the inputs of the control unit, and a second input of the second switch and the output of the minimal signal extractor being used respectively as the outputs of the control unit.

8. A device as claimed in claim 7, wherein the
- 30 end-of-cathode sputtering acknowledgement circuit comprises a comparator, a reference voltage source and a time counter, a first input and the output of the comparator being coupled respectively to the reference voltage source and to the input of the time
- 35 counter, a second input of the comparator and the output of the time counter being used respectively as the output of the end-of-cathode sputtering acknowledgement circuit.

9. A method of control of chemico-thermal treatment of a workpiece in a glow discharge, substantially as hereinbefore described with reference to the accompanying drawings.

10. A device for performing a chemico-thermal treatment upon a workpiece substantially as
- 45 hereinbefore described with reference to the accompanying drawings.